A Process for Assessing Emergent Web Mapping Technologies

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Abstract. The current pace of technological innovation in web mapping offers new opportunities and creates new challenges for web cartographers. The continual development of new mapping applications and solutions produces a fundamental tension: the more flexible web mapping options become, the more difficult it is to maintain fluency in using and teaching these technologies. We address this tension by describing a case study *process* completed to meet the needs of the University of Wisconsin–Madison Cartography program. Specifically, we conducted a sequence of three studies: (1) a competitive analysis study of contemporary web mapping technologies, (2) a needs assessment survey of internal designers/developers regarding past experiences with these technologies, and (3) a diary study charting the implementation of a subset of potentially viable technologies for the program. The process successfully achieved the goal of identifying an appropriate suite of web mapping technologies for the UW program, but also revealed broader insights into web map design as well as ways to cope with evolving web mapping technologies.

Keywords: web mapping, UI design, user-centered design, open source technology, cartographic education, Leaflet, OpenLayers, D3, Google Maps API

1. Introduction

The current pace of innovation in Web Cartography is spectacular, with new releases of or substantial updates to web mapping technologies occurring almost daily (Haklay et al. 2008, Harrower 2008). However, the ever-evolving nature of technology results in a fundamental tension for cartographers. On

one hand, the increasing flexibility and interoperability of web mapping technologies open new opportunities for web mappers; cartographers can do more now than ever. On the other hand, as technology evolves, so does the solution space from which cartographers can draw; it is increasingly difficult to establish and maintain one's bearings within this increasingly complex array of technologies. The research reported here addresses this technological tension by proposing a **process**—or streamlined, yet flexible sequences of stages for approach cartographic design (e.g., Roth et al. 2009, Robinson et al. 2012)—to assess emergent **web mapping technologies**—or the compilation of framework, libraries, APIs, services, etc., that altogether enable the creation and dissemination of web maps (Kraak & Brown 2001, Peterson 2003).

Our motivation for this work was two-fold. First, a refresh of the University of Wisconsin–Madison (UW) Cartography lab exercises was needed in response to a broader shift in client-side web mapping away from standalone, proprietary technologies (e.g., Adobe Flash) and towards open technologies that leverage the HTML5/CSS3 web standards and JavaScript[1]. Second, the process served the purpose of building institutional knowledge on web mapping within the UW Cartography Laboratory, a research and technology center providing oncampus cartographic services and apprenticeship opportunities for students. Because of the dual goals, we designed the process to be generic, allowing for potential application by other university programs, government agencies, and cartography firms grappling with similar issues in technological change. Further, we designed the process for repeated application, allowing for continued maintenance of the UW program as web mapping technology changes.

The paper proceeds with four additional sections. In the following section, core influences on the process from user-centered design are outlined. The three-stage, case study process is described in the third section, while the results from each stage are described in the fourth section. The fifth and final section is reserved for concluding remarks.

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[1] At the time of this writing, web mapping design/development is taught in the advanced UW Cartography courses only; introductory courses on static mapping using industry-standard commercial software (e.g., Adobe Creative Suite, ArcGIS) remain an integral component of the curriculum. Server-side technologies (e.g., PostGIS) are treated in a different GIS course and thus are not considered in this research, despite their acknowledged importance. All courses pair lab exercises with lectures drawing from theory and practice.

2. Background

The case study process for adapting to evolving web mapping technology was informed by scholarship from the field of Usability Engineering (Nielsen 1993, Haklay 2010). Despite their title, usability engineers seek to identify the appropriate tradeoff between the usability (i.e., ease-of-use) and utility (i.e., usefulness) of an application, identifying missing or unneeded **functionality** from the system and critical issues in evoking this functionality for completing the users' goals (Fuhrmann et al. 2005, Robinson et al. 2011). Arguably, the best way to resolve this trade-off is to seek input from the targeted end users of the application, an approach described as **user-centered design** (Norman 1988). User-centered design has been an active area of research within Cartography for over a decade (e.g., Buttenfield 1999, Gabbard et al. 1999, Andrienko et al. 2002, Slocum et al. 2003, Fuhrmann et al. 2005, Robinson et al. 2005, Haklay et al. 2008) and increasingly is applied for the design and evaluation of web maps (e.g., Haklay & Tobón 2003, Kramers 2008, Nivala et al. 2008, Roth & Harrower 2008, Çöltekin et al. 2009, Roth et al. 2010).

User-centered design relies on the elicitation of feedback on prototypes using archival or empirical methods. Many of these methods are qualitative and originate from social science, although there is a growing suite of methods specific to user-centered design (Marsh & Dykes 2008). Roth (2011a) provides a listing of common methods in Usability Engineering, organizing methods according to the source of feedback (*Figure 1*). Importantly, Nielson (1993) recommends a **discount** approach to user-centered design, recruiting a small number of participants (n=3-5) for each method to ascertain input and feedback quickly. Findings generated across multiple, discount evaluations can be triangulated to produce broader insights, an approach to design/development described as **convergent methods** (Buttenfield 1999).

Regarding web mapping technologies, the term *user* describes the designers/developers of web maps as much as it does the audience of the resulting web maps. For the case study reported here, targeted users include senior undergraduate and graduate level students with at least one prior course in map design, GIS, and programming. The process described in the following section uses a discount, yet convergent, approach for evaluating web mapping technologies to efficiently, yet reliably, collect information regarding the appropriate choice of technology for the case study context.

	Method	Similar or Related Methods
Expert-based	heuristic evaluation	*rules of thumb*
	conformity inspection	*feature inspection, consistency inspection, standards inspection, guideline checklist*
	cognitive walkthroughs	*pluralistic walkthroughs, prototyping, storyboarding, Wizard of Oz*
Theory-based	scenario-based design	*personas, scenarios of use, use case, context of use, theatre*
	secondary sources	*content analysis, competitive analysis*
	automated evaluation	*automated interaction logs, unmoderated user-based methods*
User-based	participant observation	*ethnographies, field observation, MILCs, journal/diary sessions, screenshot captures*
	surveys	*questionnaires, entry/exit surveys, blind voting, cognitive workload assessment*
	interviews	*structured interviews, semi-structured interviews, unstructured interviews, contextual inquiry*
	focus groups	*supportive evaluation, Delphi*
	card sorting	*Q methodology, concept mapping, affinity diagramming, brainstorming*
	talk/think aloud	*verbal protocol analysis, co-discovery study*
	interaction study	*performance measurement, controlled experiments*

Figure 1. User-centered design methods organized by source of feedback. Expert-based methods describe evaluations by experienced consultants. Theory-based methods describe evaluations by designers/developers. User-based methods describe evaluations by the targeted user group. While elicitation of feedback from users is recommended (hence *user*-centered design), it may not be feasible to recruit users given the stage in design and project resources. Figure redrawn from Roth (2011a).

3. Methods

Following a user-centered approach, three studies were selected from *Figure 1* and administered in sequence: (1) a competitive analysis study, (2) a needs assessment survey, and (3) a diary study. The three-stage process was designed to narrow iteratively the complete set of technologies, ultimately identifying a technology solution suitable for the case study context (but not necessarily all web mapping contexts). The selected methods allow for the process to be completed by a small team of designers/developers (n=3-5) within a two week exploratory period directly following a request for proposals or project kickoff.

3.1. Competitive Analysis Study

A competitive analysis study first was conducted to collect and evaluate all available web mapping technologies. A **competitive analysis** is a theory-based method based on secondary sources that critically compares a suite of related applications according to their relative merits (Nielsen 1992). Completing a new competitive analysis at the start of each project is essential, given the pace of technological change in web mapping.

The project team collected links to websites (the secondary sources) for all JavaScript web mapping technologies over a two-week period in Spring 2012, making use of keyword searches, popular blogs, and social media to find the technologies. Over 30 open-source or pay-service JavaScript technologies were identified in total[2] (*Figure 2*). Two project members then independently coded the technologies according to the available **representation** functionality for graphically encoding information and **interaction** functionality for building user interfaces to modify the representation (Roth 2011b); the codes themselves were derived from primary topics covered in lecture. Several non-JavaScript technologies (e.g., GeoMoose, OpenScales, Processing) are included in *Figure 2* for comparison in functionality to JavaScript technologies.

Project team members were instructed to apply the representation and interaction codes based on the documentation included within or linked from the websites, without experimenting with the code itself. Such an approach at the first stage in the process follows discount, convergent user-centered design. This approach is further justified by the targeted user group—students—who need clear and comprehensive documentation to learn new technologies. A four point ordinal scale was applied during coding: (1) supported, (2) known work-around, (3) requires hack, and (4) not possible.

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[2] Over a dozen more have been collected in the year following the formal competitive analysis.

3.2. Needs Assessment Survey

Following the competitive analysis study, a needs assessment survey was administered across the UW System (26 campuses) to elicit past experiences with the collected technologies as well as currently unmet web mapping needs. A **survey** is a user-based method that requires participants to respond to predetermined questions (Suchan & Brewer 2000). The survey was included as the second step in the process to acquire feedback about the collected technologies from targeted users outside of the project team; the survey was administered online following the discount, convergent approach.

Twenty-one UW System employees participated in the needs assessment survey. Participation was limited to employees who either design/develop web maps or who supervise such design/development. The question protocol was divided into four sections: (1) basic biographic information, (2) current use of the technologies identified in the competitive analysis, (3) aspects of technologies that should be considered when selecting a technology, and (4) overarching opinions on designing web maps and teaching web map design. The non-biographical portion of the survey included 12 questions in total, with four Likert scale questions (*Figures 3* & *4*) and eight free response questions. The needs assessment survey was designed to take 15 minutes.

3.3. Diary Study

Insights from the competitive analysis study and needs assessment survey were combined to identify a subset of four **candidate technologies** believed to be viable options that may support the case study context. A **diary study** is a variation of the user-based participant observation method that requires participants to *self-observe* as they complete an activity. The diary study provided the deep experience working with a specific technology needed to identify an appropriate solution, but does so in a discount, convergent manner by relying on prior methods to reduce the total number of technologies under consideration; the self-observation further restricts impact on project resources.

Four students representative of the targeted user group were recruited to complete an example web mapping scenario using one of the four assigned technologies (*Figure 5*); a fifth student completed the same scenario with all four technologies to improve reliability across participants (n=8 diaries). The scenario included 24 functional requirements in total, split between representation and interaction (*Figure 6*).

Participants were given a total of 40 hours to complete as many of the requirements as possible, mimicking constraints of an average work week. Students were not expected to complete all 24 requirements within the provided time period; the accomplished requirements therefore indicate the most straightforward functionality supported by the technology. Participants were required to log a diary entry every hour (40 entries total), with each entry including notes on the accomplished requirements in the past hour, key frustrations or breakthroughs, and their current satisfaction with the technology drawing from a provided list of emotions. Participants also were required to capture a screenshot of the web map and a version of their code with each diary entry (Haklay & Zafiri 2008). An exit survey was administered after reaching the 40 hour period to elicit additional feedback.

4. Results and Discussion

4.1. Competitive Analysis Study

Results of the competitive analysis are illustrated in the *Figure 2* matrix. Horizontally, the matrix reveals variation between specialist technologies designed to support specific functions (e.g., CloudMade Editor, Mapnik) and multi-purpose technologies supporting numerous functions (e.g., D3, Google Maps, Leaflet, OpenLayers). Individual technologies generally fall into one of the following categories: (1) frameworks (e.g., GeoMoose, MapServer), (2) open libraries (e.g., D3, Modest Maps, Leaflet, OpenLayers, Polymaps, Raphaël), (3) closed APIs (e.g., Bing Maps, Google Maps, MapQuest), and (4) tile rendering services (e.g., Cloudmade, Mapnik, TillMill, TileStache). Given the curricular goals of teaching JavaScript specifically along with web map design generally, an emphasis was placed on open libraries that can be combined with other JavaScript libraries (e.g., jQuery); an exercise in tile rendering will be added in the future to an advanced graphic design course in Cartography.

Verticially, the matrix provides a snapshot of trends in contemporary web map design. Widely supported representation functionality includes loading of vector or imagery basemaps, custom vector overlays, and choropleth or proportional symbol thematic maps. Widely supported interaction functionality includes panning, zooming, overlay of context layers, and retrieval of details using an information window; these four interaction operators altogether form the growing *slippy* web map design convention, showing that this convention may be driven by limitations in the existing

technologies, rather than by the actual needs of web map users. The functionality with the greatest variation across technologies include basemap styling and tile rendering for the representation category—explained by inclusion of custom rendering services in the matrix—and dynamic reprojection for the interaction category—showing the growing dependence on tile basemaps using cylindrical projections.

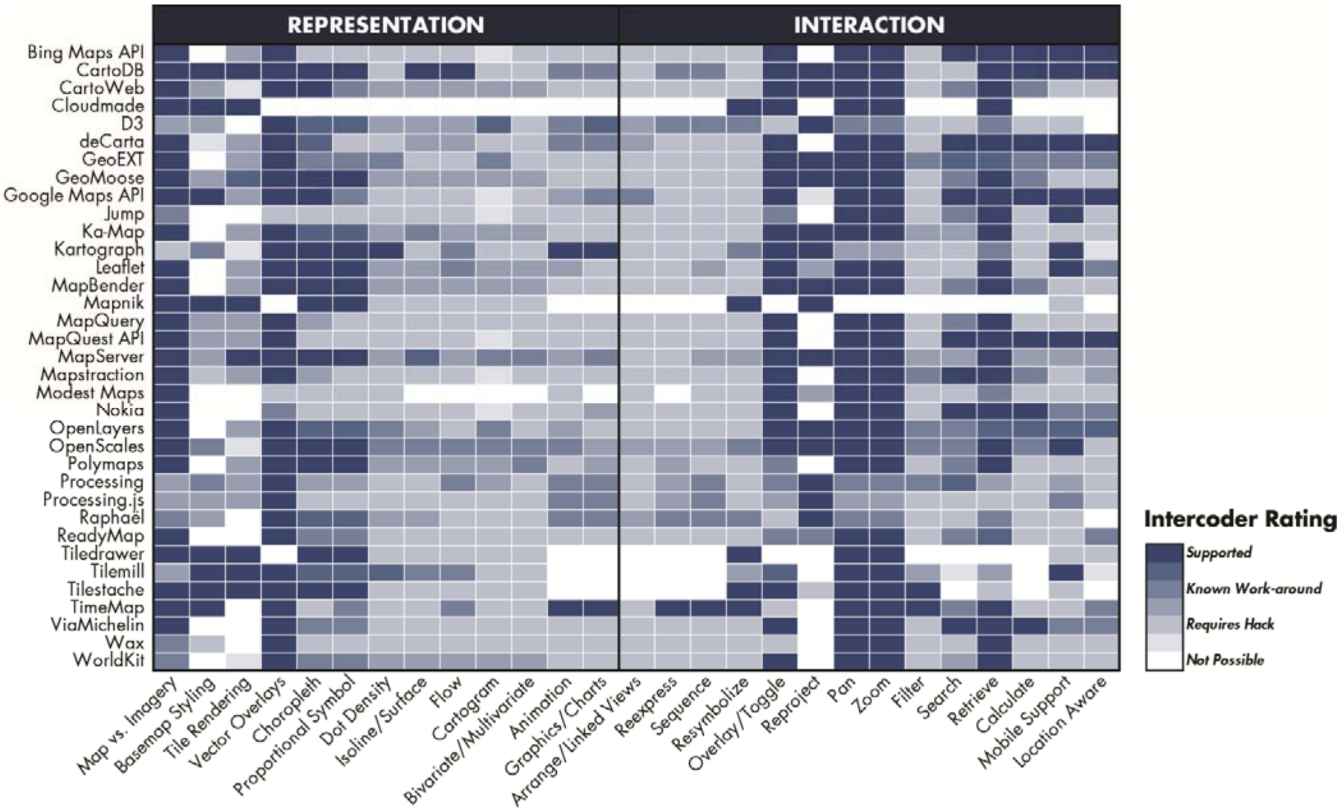

Figure 2. Results of the competitive analysis study. Collection and coding was completed in Spring 2012; therefore, the matrix is no longer complete nor accurate, although arguably it never can be given the speed of technological advancements in web mapping.

4.2. Needs Assessment Survey

For space, discussion of the needs assessment survey is limited to participant responses to the Likert scales; however, the free response questions provided valuable clarification needed to interpret the Likert scale ratings. UW System employees make use of only a subset of technologies identified through the competitive analysis (*Figure 3*). Only the Google Maps API was used by a majority of participants in the past year (n=11), with OpenLayers (n=9), ArcGIS Server (n=8), and Adobe Flash (n=6) used in the past year by a large minority. Interestingly, participants had not heard of a majority of the technologies, reinforcing the fast pace of technological change in web mapping.

Please rate your engagement with the following web map technologies

	I have not heard of this technology	I am aware of this technology, but have not used it for any projects yet	I have used this technology in the past, but it was more than one year ago	I have used this technology in the past year
ArcServer	0	11	2	8
Adobe Flash	0	11	4	6
Adobe Flex	2	13	2	4
Bing Maps API	0	15	2	4
CartoDB	13	8	0	0
CartoWeb	15	5	0	1
Cloudmade	13	5	0	3
D3	17	3	0	1
deCarta	12	9	0	0
GeoEXT	13	5	1	2
GeoMoose	6	12	1	2
Google Maps API	1	6	3	11
Jump	16	5	0	0
Ka-Map	14	7	0	0
Kartograph	17	4	0	0
Leaflet	13	4	0	4
MapBender	13	8	0	0
Mapnik	9	10	0	2
MapQuery	16	4	0	1
MapQuest API	1	17	2	1
MapServer	3	8	5	5
Mapstraction	13	7	0	1
Modest Maps	12	7	1	1
Nokia	11	10	0	0
OpenLayers	3	6	3	9
OpenScales	18	3	0	0
Polymaps	15	6	0	0
Processing	16	4	1	0
Processing.js	16	4	1	0
Raphaël	12	7	1	1
ReadyMap	18	3	0	0
Tiledrawer	19	2	0	0
TileMill	10	7	1	3
Tilestache	15	6	0	0
TimeMap	19	1	1	0
ViaMichelin	20	1	0	0
Wax	19	2	0	0
WorldKit	15	5	0	1

Frequency
n=21
n=0

Figure 3. Results of the needs assessment survey: level of engagement with existing web map technologies.

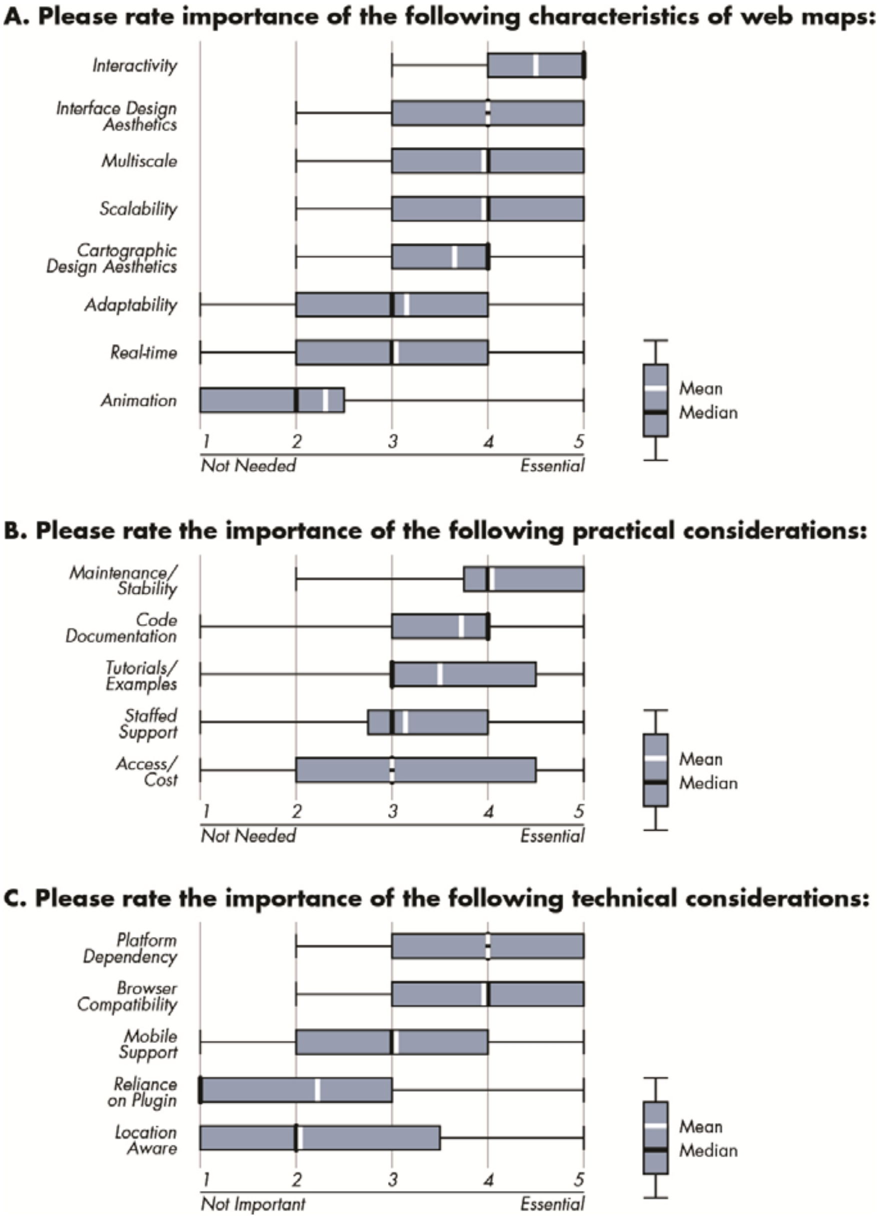

Figure 4. Results of the needs assessment survey: **(a)** web map characteristics; **(b)** practical considerations; **(c)** technical considerations.

The additional Likert scale questions identified aspects of web mapping technologies that must be considered when selecting an appropriate solution. Participants rated interactivity as the most essential characteristic of web maps, with animation listed as the least essential (*Figure 4a*). Participants rated maintenance/stability as the most important practical consideration and were divided evenly on access/cost, indicating a split in open source versus commercial technologies across the UW System (*Figure 4b*). Participants rated platform dependency and browser compatibility as the most important technical considerations, with location awareness rated as least important (*Figure 4c*); this latter ranking provides an indication that many centers in the UW System have yet to make the jump to mobile at the time of testing.

4.3. Diary Study

Insight from the competitive analysis and needs assessment were triangulated to identify four candidated technologies: three open libraries (D3, Leaflet, and OpenLayers) and one closed API (Google Maps) (*Figure 5*). Google Maps was included due to its frequent use across the UW System and for evaluation of different learning outcomes between open libraries and closed APIs.

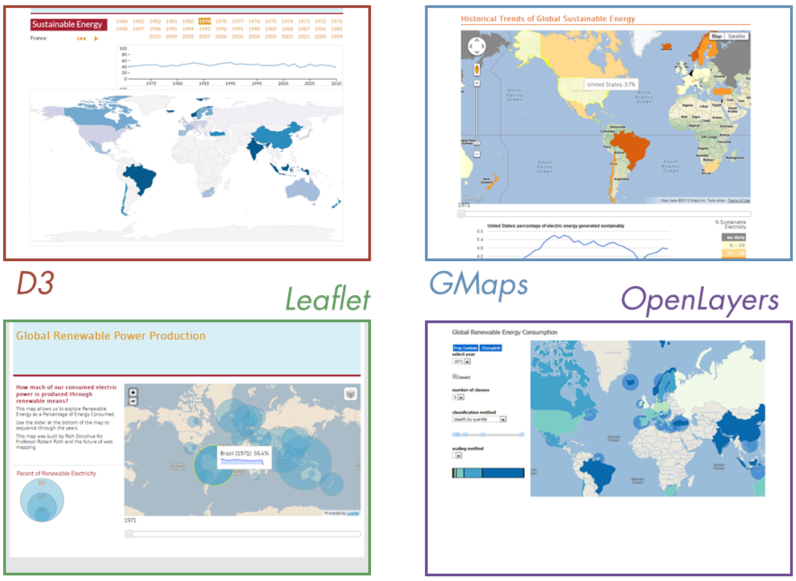

Figure 5. Example solutions for the energy web mapping scenario resulting from the diary study: **(red)** D3; **(blue)** Google Maps; **(green)** Leaflet; **(purple)** OpenLayers.

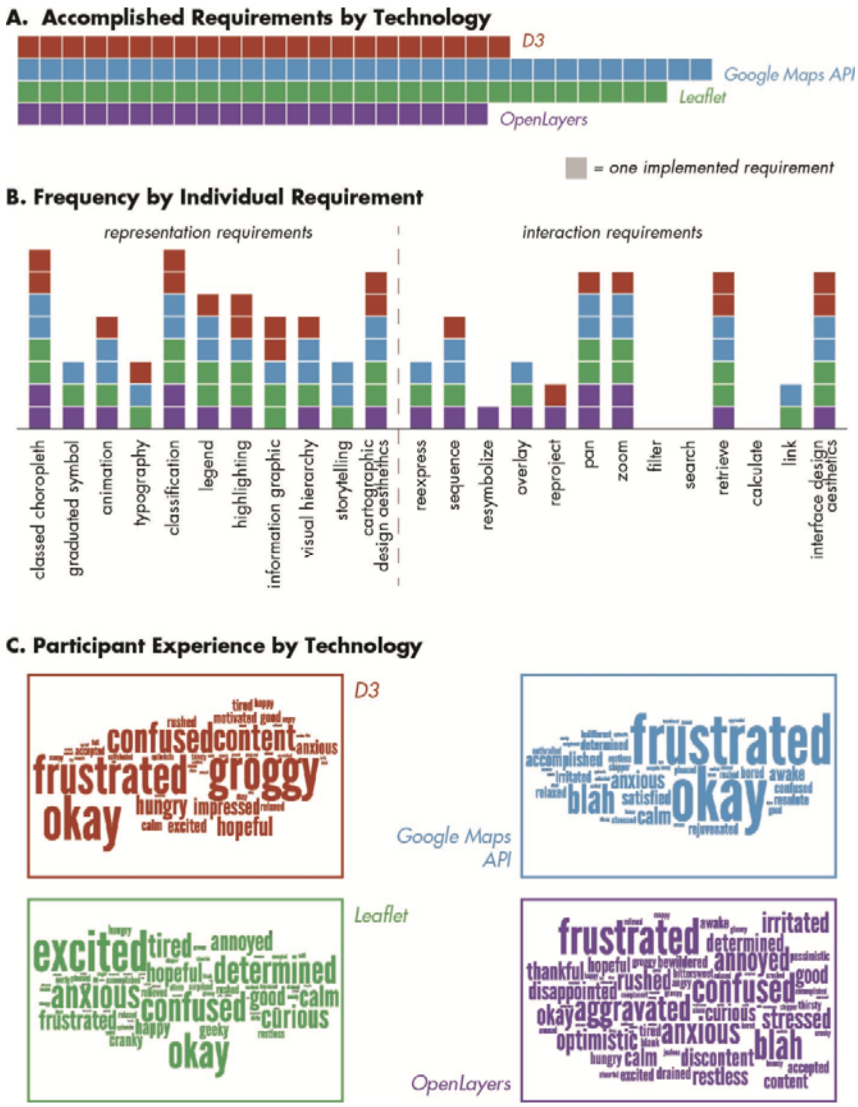

Figure 6. Results of the diary study: **(a)** total frequency of accomplished requirements by technology; **(b)** frequency of individual accomplished requirements; **(c)** participant experience by technology, according to reported emotional descriptions.

Figure 6 presents an overview of the diary study results. Again, each candidate technology has a pooled sample size of two, resulting in a maximum of 48 requirements per technology (2x24). On average, participants completed the most scenario requirements using the Google Maps API (n=31), with Leaflet a close second (n=29); fewer requirements were accomplished with D3 (n=22) and Open Layers (n=21) (*Figure 6a*). There was substantial variation in the final maps by individual requirement, with the choropleth map and dynamic classification the only features implemented at least once using all four technologies; the interaction functions calculate, filter, and search were not implemented in any web map (*Figure 6b*). Interestingly, participant experiences with Leaflet were deemed more satisfying and less frustrating than the others, despite the Google Maps API resulting in the greatest number of implemented requirements (*Figure 6c*). Descriptions in the diaries and exit survey suggested that the open nature of the Leaflet code library, as well as its clear and comprehensive documentation, made the initial learning of Leaflet easier than the other alternatives.

5. Conclusion

The research presented here describes the use of a process for keeping pace with emerging web mapping technologies. Drawing upon key concepts in user-centered design, the process supports the identification of an appropriate technological solution—or combination of solutions—for a specific web mapping context. The purpose of the process is *not* to find an overall winner for all web mapping contexts, but to remain malleable as web mapping technology changes. Further, the process is designed to be completed by a small development team within a two week period and makes use of a discount, convergent approach to make efficient use of project resources.

As a result of the process, we began using Leaflet in Fall 2012 as the base JavaScript library for the UW Cartography program, providing advanced labs that use pieces of D3 and the Google Maps API once JavaScript is learned. The lab instructions and source code resulting from this project are available for download on Github: http://www.github.com/reroth/g575-2013. The process will be administered regularly through the UW Cartography Lab—with the laboratory curriculum revised accordingly—to ensure that the UW-Madison Cartography program continues to evolve along with emergent web mapping technologies.

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